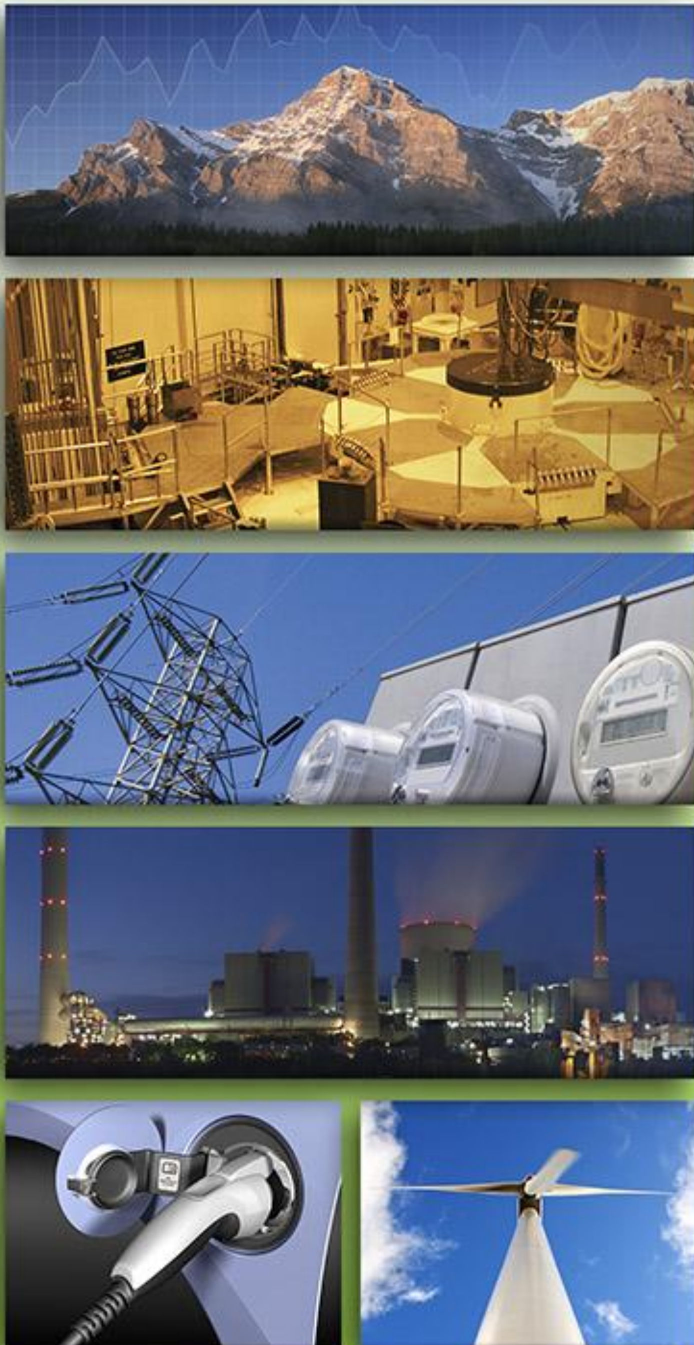


EPRI | ELECTRIC POWER RESEARCH INSTITUTE

EPRI Activities Related to Advanced Nuclear Power and Fuel Cycles

John Kessler
Manager, Used Fuel and High-Level Waste Management Program

Blue Ribbon Commission, Fuel Cycle Subcommittee Meeting
12 July 2010

Outline

- EPRI Nuclear R&D areas
- U.S. Nuclear Fleet Outlook
- Advanced Nuclear Technology
- Fuel Reliability Issues
- Used Fuel and High-Level Waste Management
  - Advanced fuel cycle studies
  - Readiness of U.S. fleet to burn MOX

The Electric Power Research Institute

RD&D for the Electricity Industry

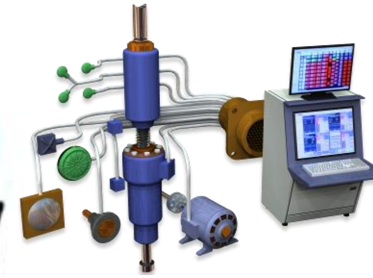
- Independent, unbiased, tax-exempt collaborative research organization
- Full spectrum industry coverage
  - *Nuclear*
  - *Generation*
  - *Environment*
  - *Power Delivery & Utilization*
- 460 participants in more than 40 countries
- Major offices in Palo Alto, CA; Charlotte, NC and Knoxville, TN

EPRI Nuclear Research Areas

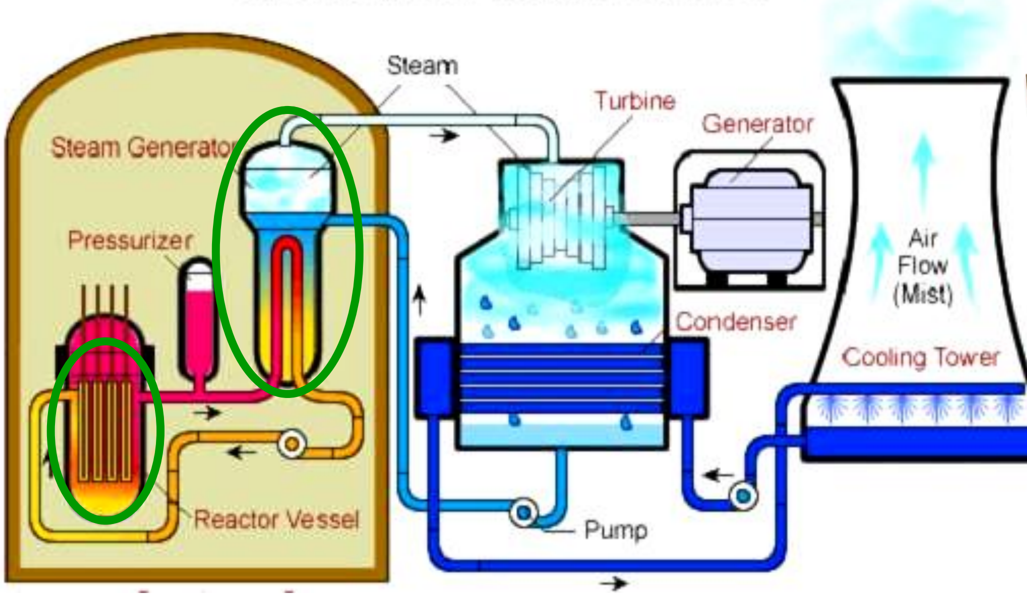
Inspection

Risk & Safety

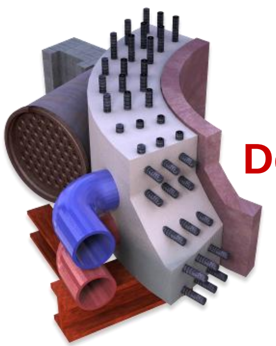
Equipment Reliability



Pressurized Water Reactor

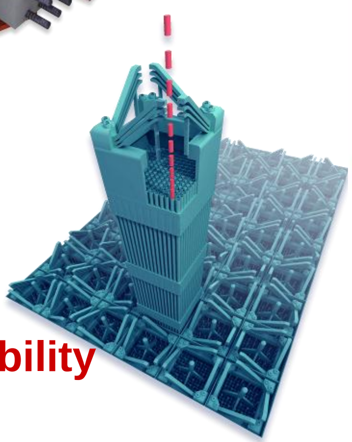


Material Degradation



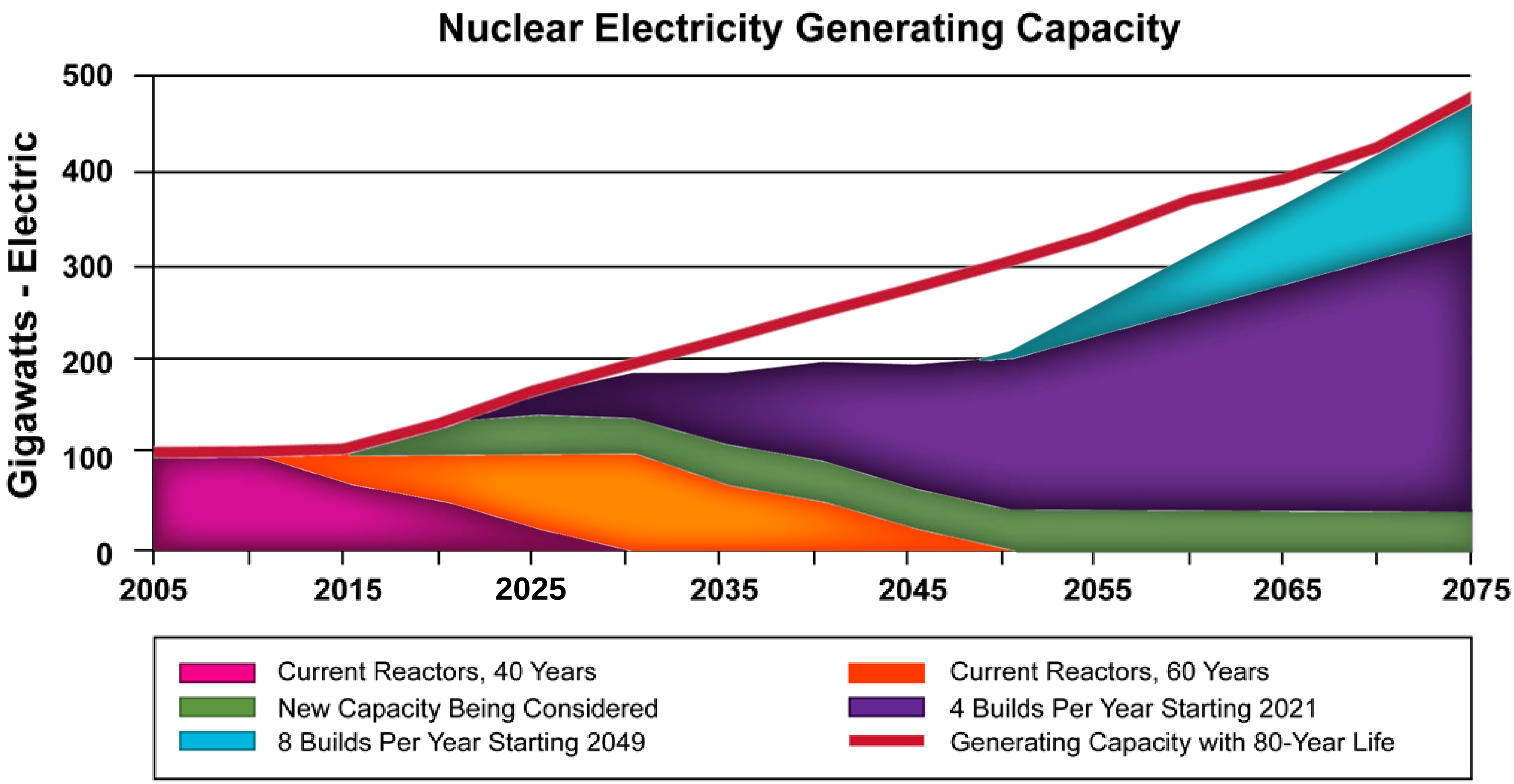
Advanced Nuclear Technology

Fuel Reliability



Radiation Exposure and Waste Management

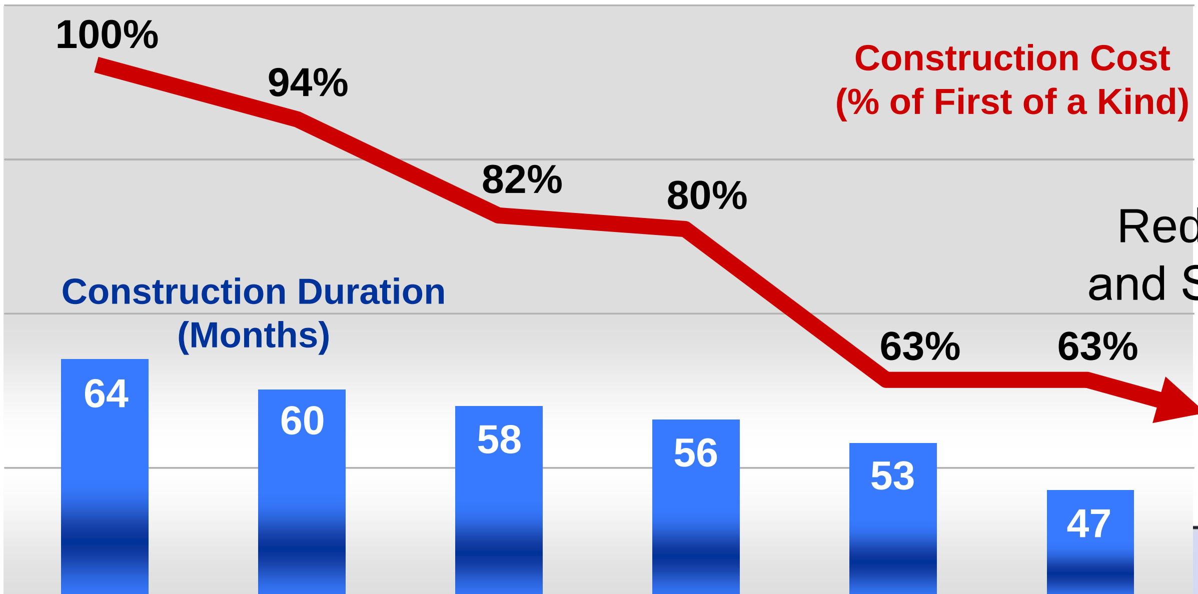
U.S. Nuclear Fleet Outlook



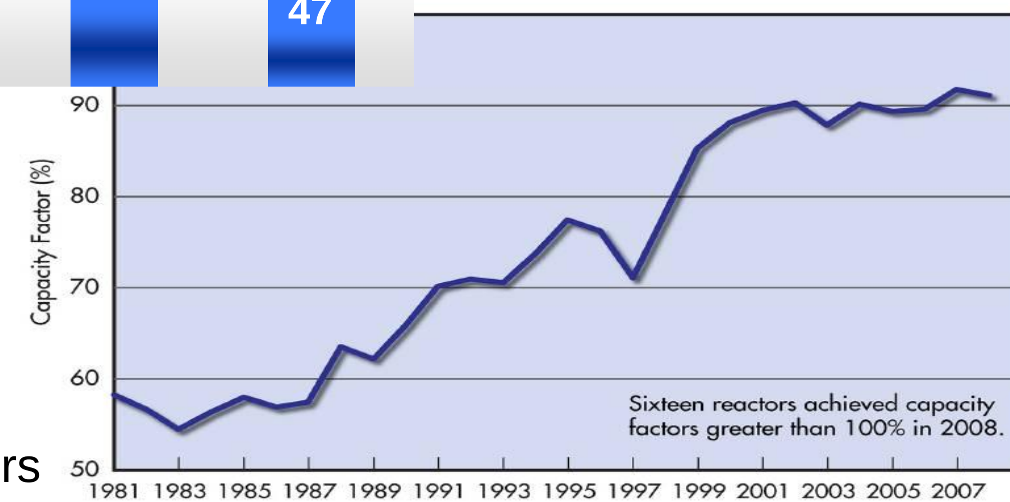
Opportunity for Economic, Low Carbon Base Load Generation

Source: DOE Life Beyond 60 Workshop February 2008

Advanced Light Water Reactor Deployment
How Do We Achieve This Performance?



Reduced Construction Costs
and Schedules…Unit Over Unit



Efficient Plant Start-Up and
Sustained High Capacity Factors

EPRI ELECTRIC POWER RESEARCH INSTITUTE

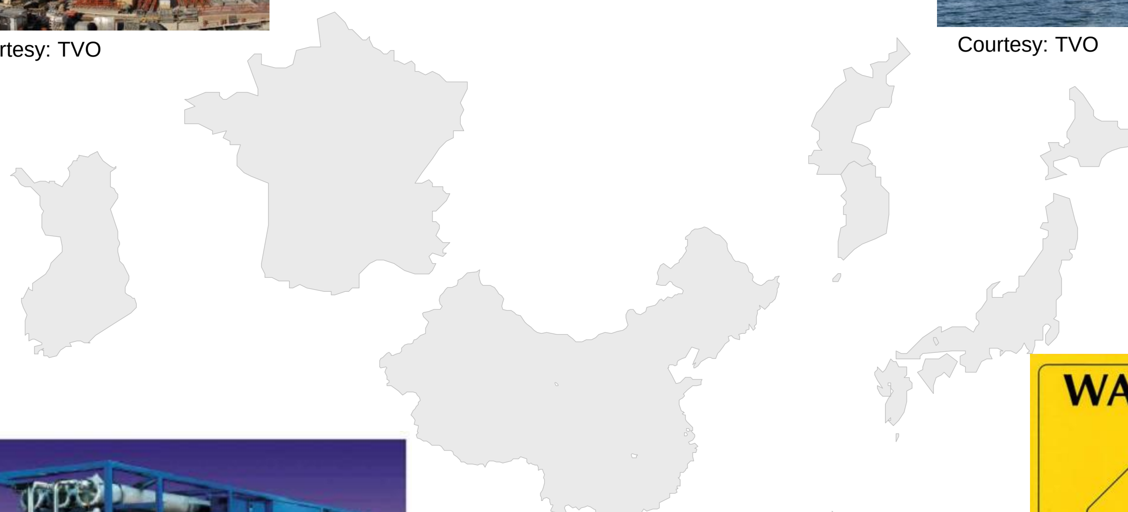
Advanced LWR Technology Deployment

Facilitate standardization across the new nuclear fleet

Courtesy: TVO

Ensure top plant performance from start of operations

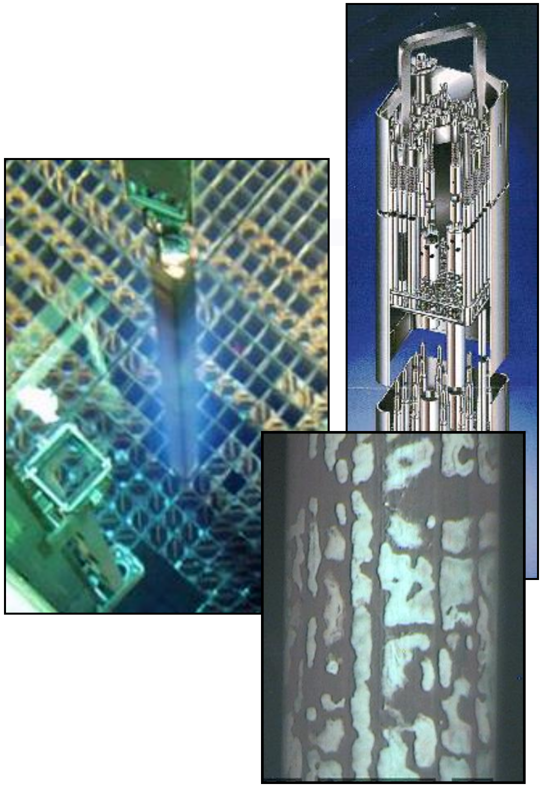
Courtesy: TVO



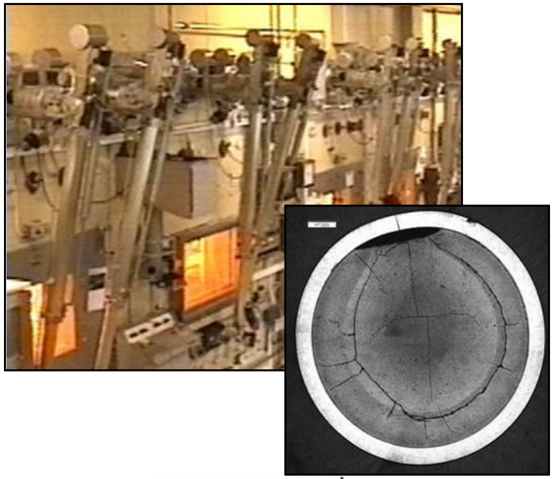
Transfer technology and lessons learned to new plant designs

Reduce overall deployment risk and uncertainty

Nuclear Fuel Issues

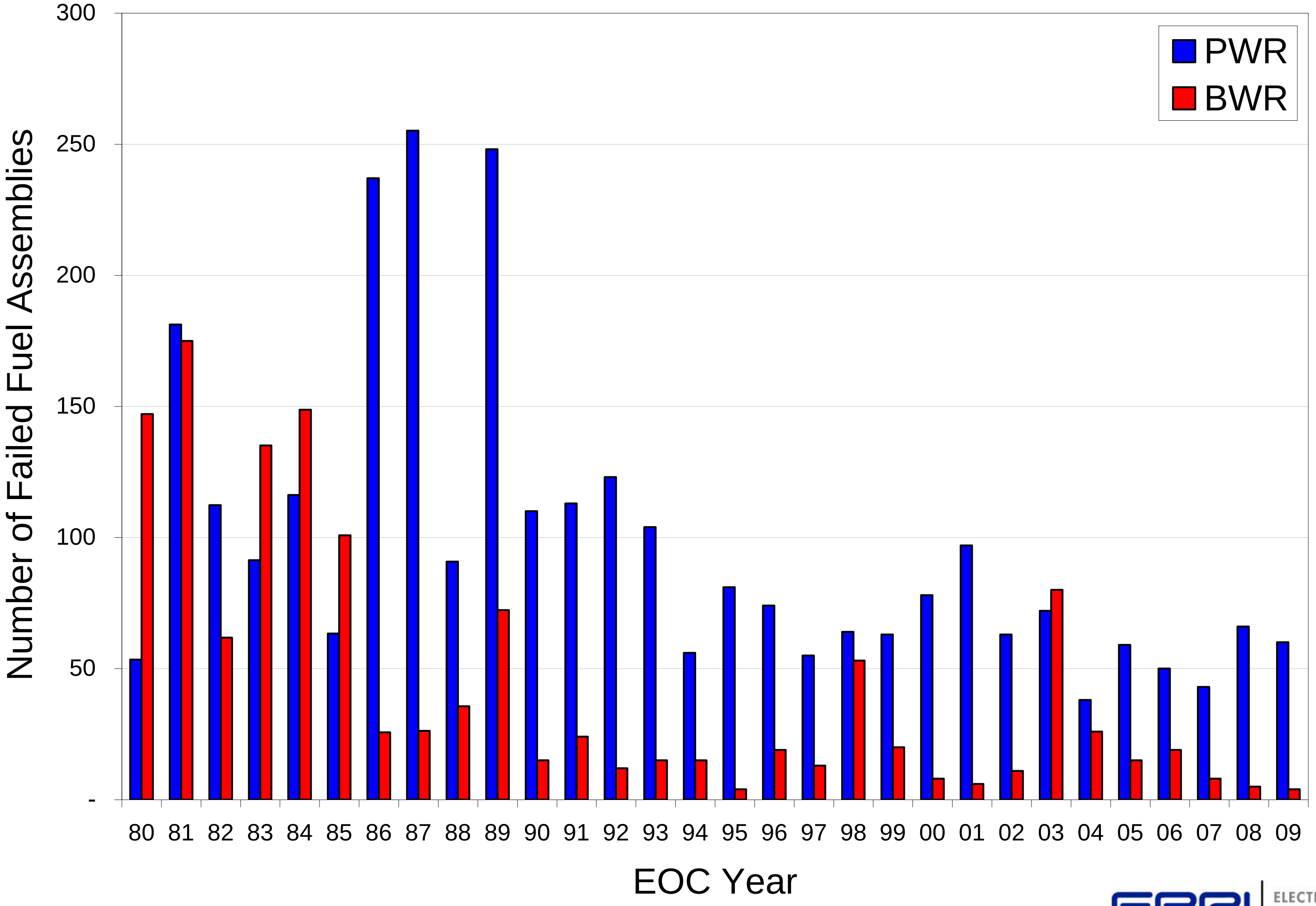


- Fuel reliability guidelines
- Failure root cause investigations
- Fuel reliability margins
- Regulatory issues
- Independent fuel performance codes
- Advanced NDE techniques



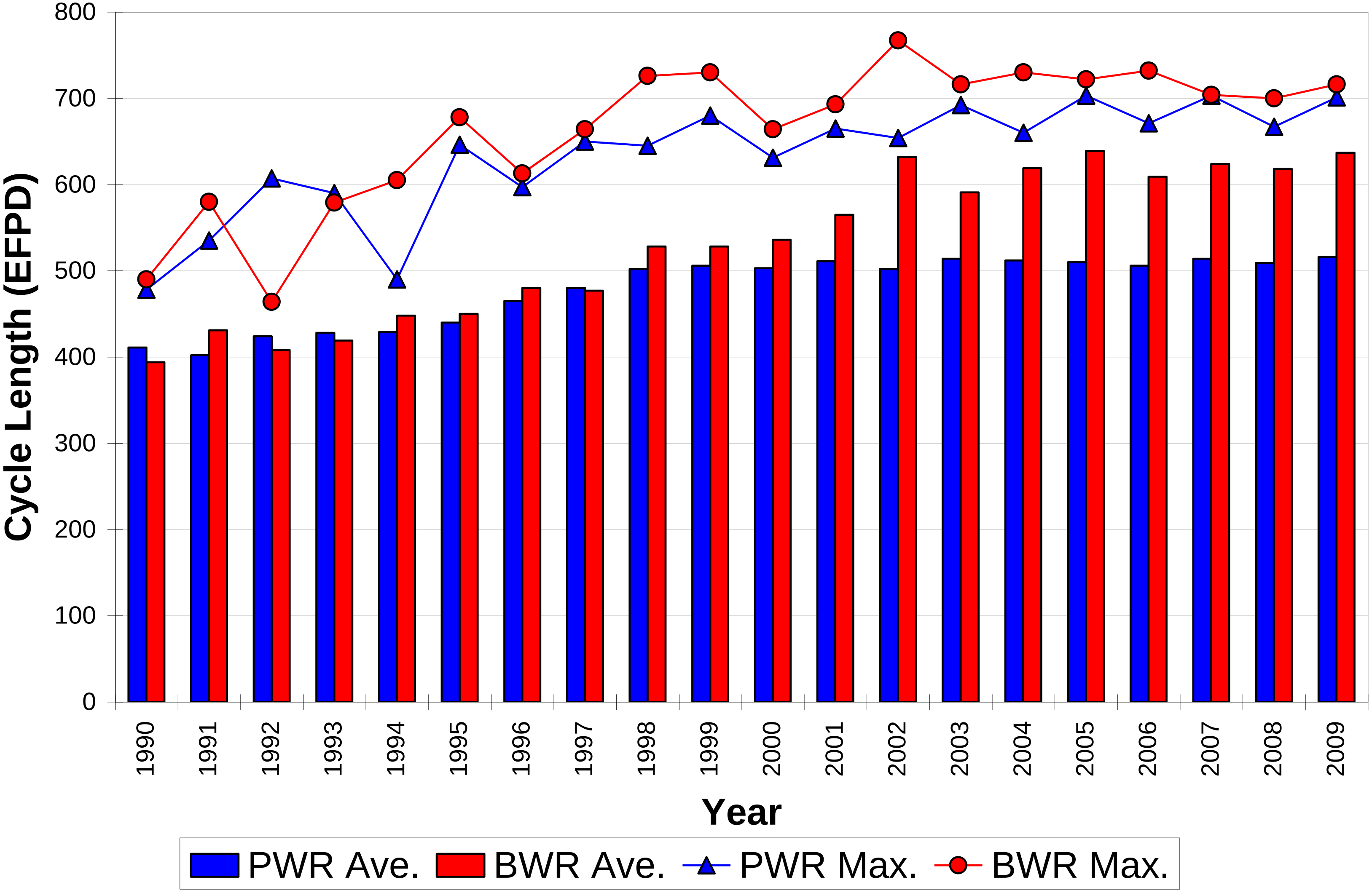
ELECTRIC POWER RESEARCH INSTITUTE

U.S. Industry Fuel Failure Trend



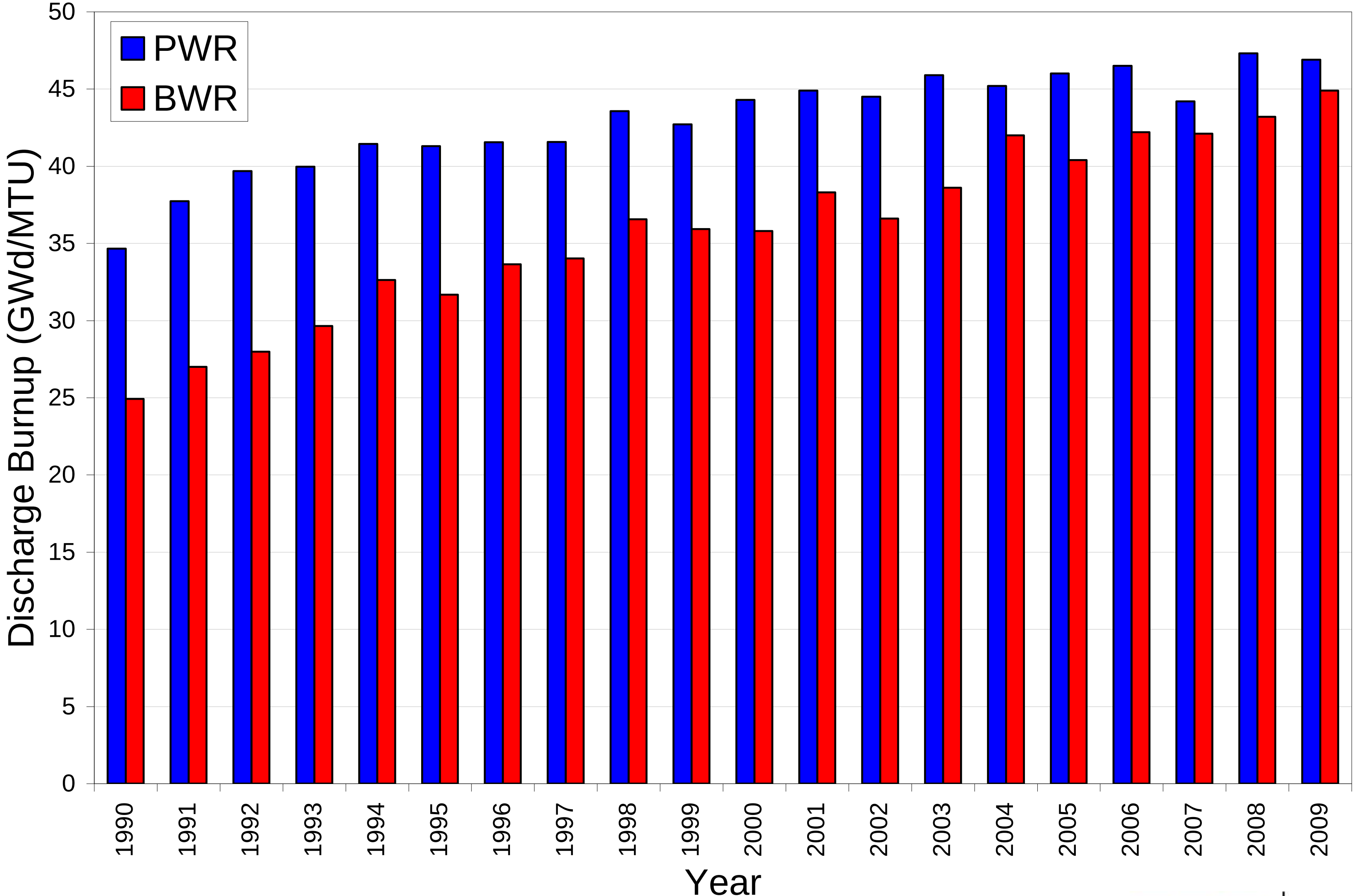
ELECTRIC POWER RESEARCH INSTITUTE

Average U.S. Cycle Length Trends



EPRI ELECTRIC POWER RESEARCH INSTITUTE

Average U.S. Discharged Assembly Burnup Trends



EPRI ELECTRIC POWER RESEARCH INSTITUTE

Advanced Fuel Designs
Silicon Carbide Fuel Cladding

- Benefits
  - Improved safety due to higher-temperature capabilities
  - Large power uprate potential
- Challenges
  - Modified fuel performance codes
  - Transient analyses
  - Basic materials properties
  - Irradiation performance
  - New fabrication and inspection technologies

Silicon Carbide Cladding

Courtesy Westinghouse and Ceramic Tubular Products

EPRI's Used Fuel and High-Level Waste Management Program

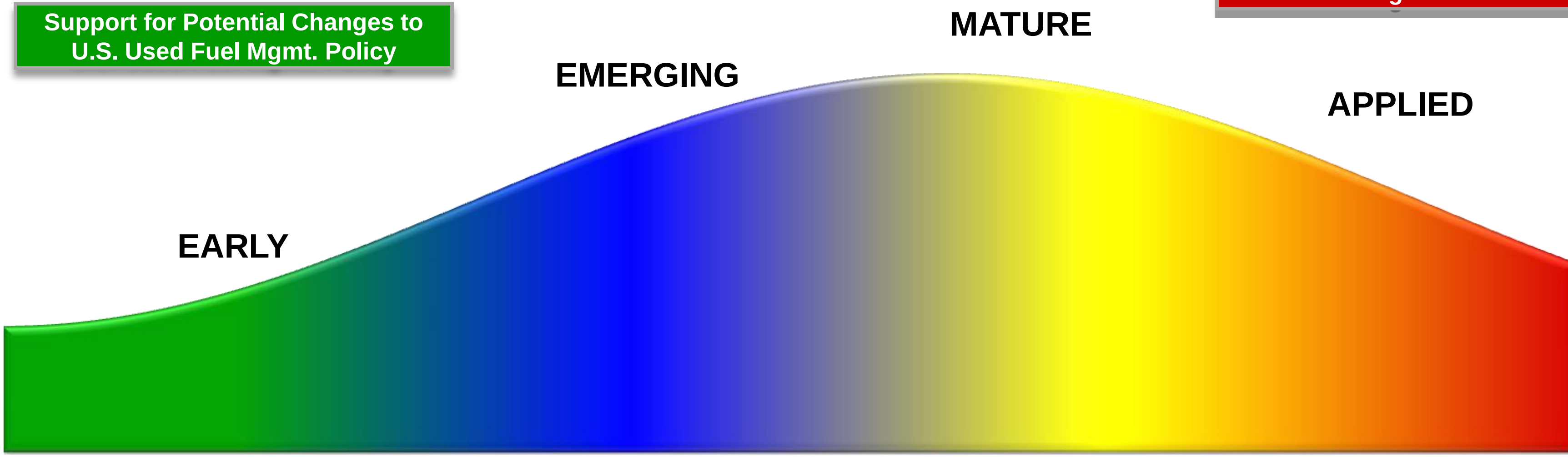
Used Fuel and Hugh-Level Waste Management *Research Elements*

- Advanced Fuel Cladding Mechanical Property Data
- Modeling of Advanced Fuel Cycles (material tracking, health risk, economics)
- Technical Bases for Very Long-term Dry Storage
- Wet Storage Criticality Modeling Benchmarking
- Support for Potential Changes to U.S. Used Fuel Mgmt. Policy

- Use of MOX in LWRs
- Technical Bases for Transportation of High Burnup Used Fuel
- Centralized Interim Dry Storage Economics

- Neutron Absorber Materials Database
- Yucca Mountain Performance Modeling

- CaskLoader
- Used Fuel Dry Storage License Extension
- Technical Bases for Yucca Mountain Regulations
- New Neutron Absorber Material (Metamic)
- Boraflex Degradation Management



EPRI Technical Perspective on Reprocessing

- 1991
  - “Adoption of a process-before-disposal policy…would accrue only modest benefits with respect to…national inventory of transuranics…”
  - “[A] process-before-disposal policy would incur a large cost penalty.”
- 1995
  - “The energy utilization benefits of the ALMR will be realized when uranium becomes more expensive… current reserves are large…”
  - “Light water reactor fuel is safe for geologic disposal…”
  - “…an integrated spent fuel management system [with] emphasis on interim storage dovetails…with a rational and deliberate process of reconsidering U.S. fuel cycle policy implementation.”

EPRI Technical Perspective on Reprocessing [continued]

- 2006
  - "The nation needs a broad consensus on which processing/fast-reactor technology combination is the best choice…"
  - "..an acceptable, affordable and reliable fast reactor appears likely to control the overall schedule and should receive appropriate development program emphasis…"
  - "Decisions on a possible second repository will not really be necessary until at least mid-century…"

Reprocessing not a clear winner under current conditions and state of technology; critical to demonstrate fast reactor technology first.

Advanced Fuel Cycle Roadmap

- EPRI role: Provide technically based, independent analysis of fuel cycle options to inform decision-makers.
- Help industry keep options open
  - Develop tools to assess nuclear fuel cycle options from an electricity generation viewpoint
  - Conduct independent assessments of current state of technology in key areas: reprocessing, fuel re-fabrication, geologic disposal media

Advanced Fuel Cycle Toolbox

1. Decision Analysis Tool
2. Risk Assessment Tool
3. Nuclear Fuel Cycle Simulation
4. Economic Modeling
5. Proliferation Resistance and Physical Protection

1. Decision Analysis Tool

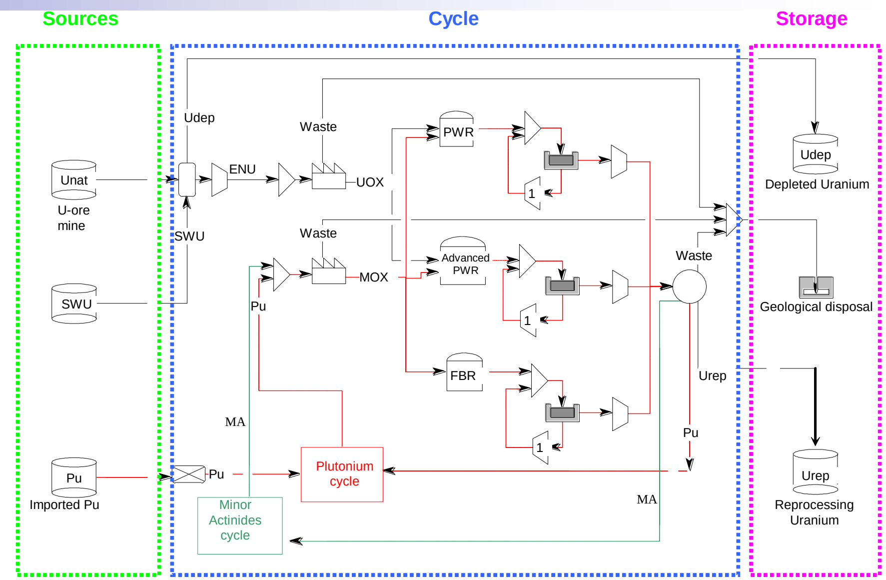
- Description
  - Tool to compare fuel cycle options based on:
    - Economics
    - Natural uranium resource amplification
    - Institutional policies
    - Risks
- Status
  - Concept being formulated at MIT
  - EPRI will evaluate need for continued development of the MIT tool

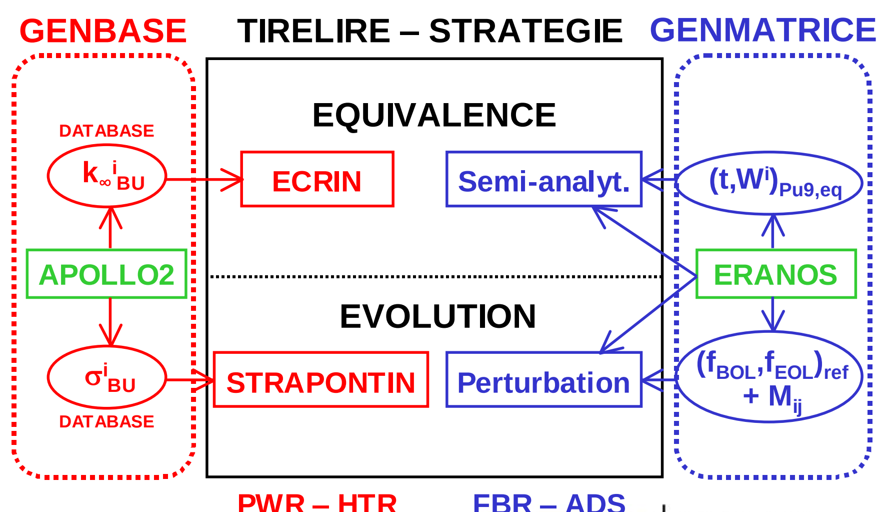
2. Risk Assessment Tool

- Description
  - Tool to compare economic and radiological risks from different fuel cycles
- Status
  - Concept being formulated at MIT
  - EPRI will evaluate need for continued development of the MIT tool
  - Opportunity to build on EPRI tools and resources for disposal performance assessments (expert team, IMARC)

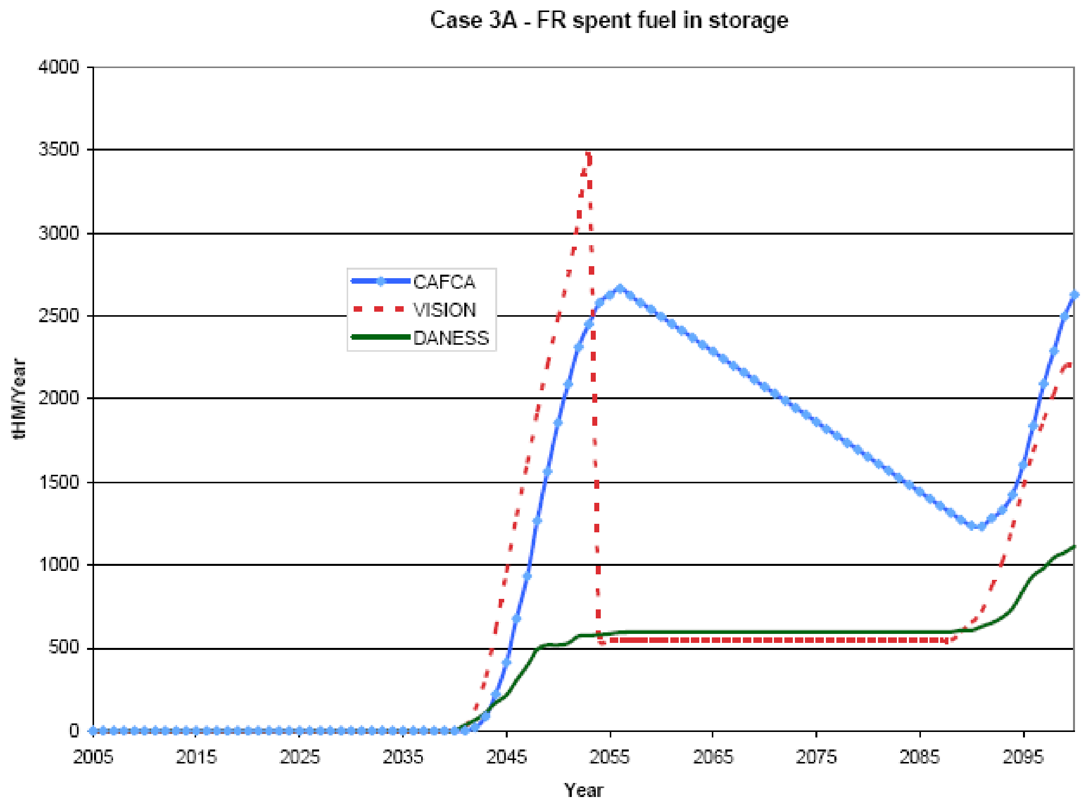
3. Nuclear Fuel Cycle Simulation Code

- Description
  - Ability to conduct dynamic (i.e., time-dependent) fuel cycle simulations
- Status
  - EPRI engaging multiple stakeholders to develop code and collect model input (EDF, INL, ANL, ORNL, MIT, others)





3. Nuclear Fuel Cycle Simulation Code (continued)



Case 3a: LWRs transition to Fast Reactors with Conversion Ratio of 1 (Electricity generation remains constant)

ELECTRIC POWER RESEARCH INSTITUTE

Transuranics Inventory

TRU Nuclide	Once-through [MT of TRU]	PWRs +Fast burner Reactors [MT of TRU]
Np-237	4.0	5.6
Pu-238	2.3	15
Pu-239	28	75
Pu-240	13.5	87
Pu-241	8.8	16.6
Pu-242	4.6	29.3
Am-241	0.32	11.6
Am-243	1.2	8.3
Cm-244	0.66	8.4
Cm-245	0.05	2.1
Total TRU	**~63**	**~259**

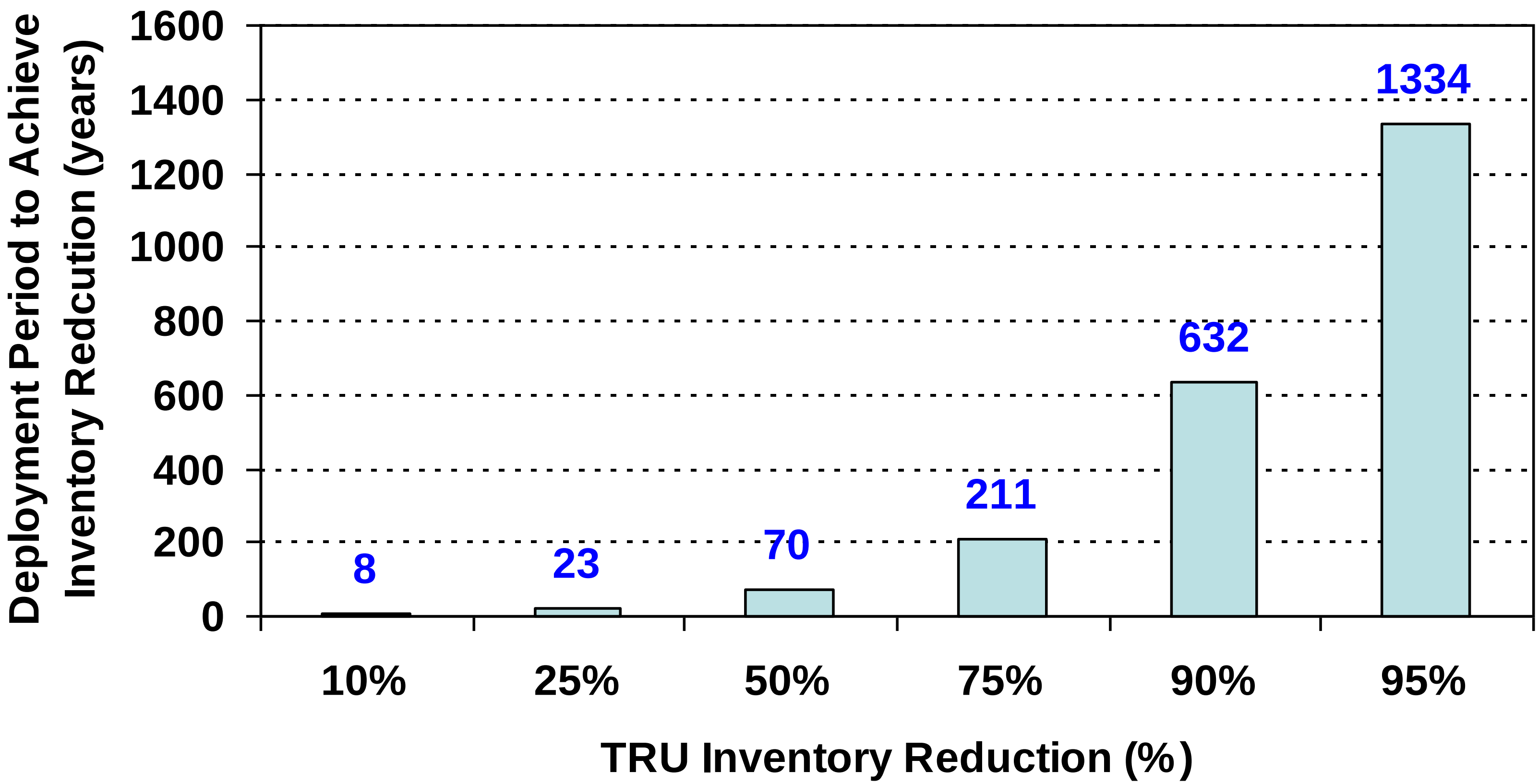
Greater TRU inventories are maintained in advanced fuel cycles than in once-through fuel cycles.

Fast Reactor Fuel Fabrication

Impact of Minor Actinide Content		+1% Np	+1% Am	+1% Cm
Fast Reactor Fuel Fabrication	Heat Release	x 1	+30%	x 10
	γ Dose	x 2	x 30	x 200
	Neutron Source Term	x 1	+15%	x 700

Short-term exposure risks with advanced fuel cycles must be weighed against long-term exposure risks with once-through fuel cycles.

Advanced Fuel Cycle Deployment
Transuranic Inventory Reductions



Many decades required to achieve even a modest TRU inventory reduction across entire fuel cycle.

4. Economic Modeling

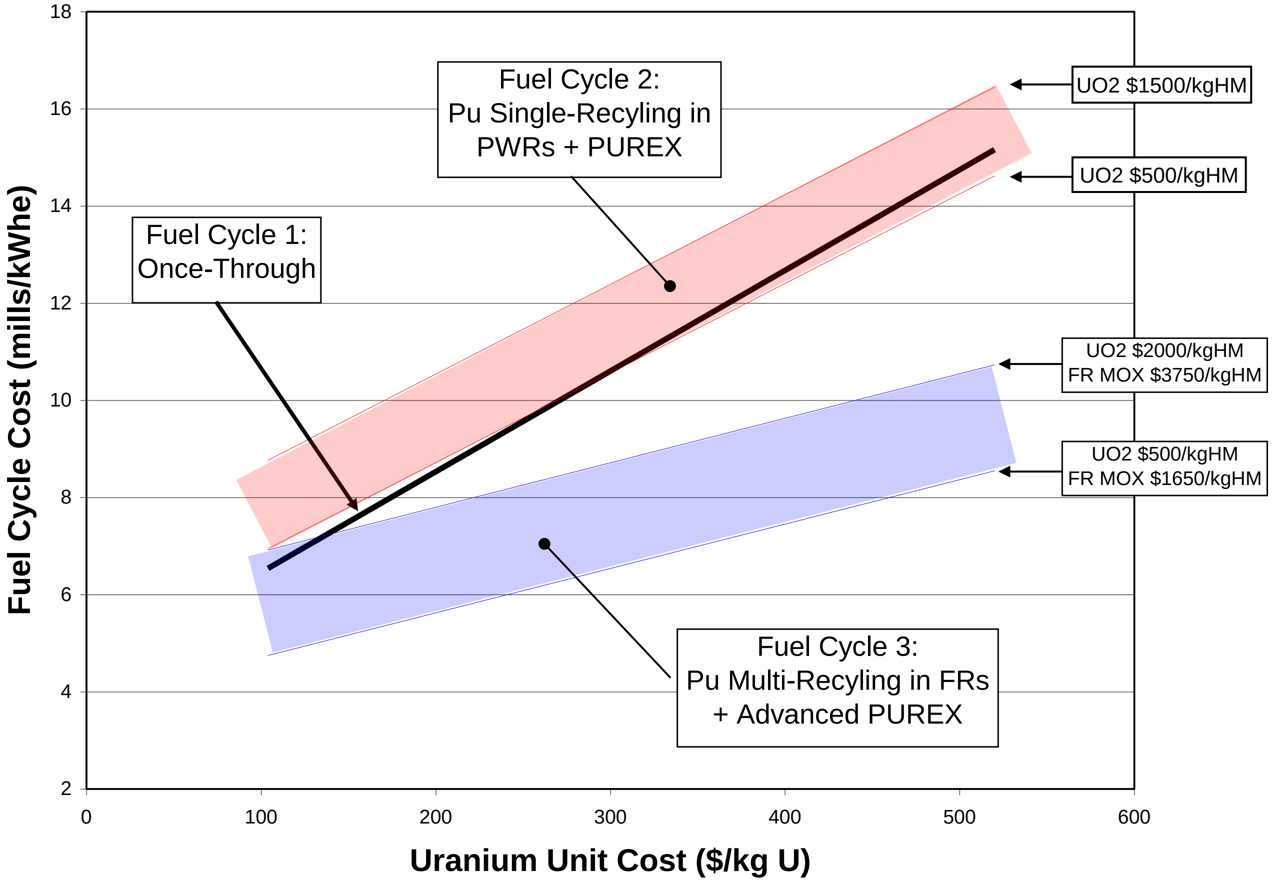
Description

- Tools to translate fuel cycle options to economic terms for both fixed and variable elements

Status

- Currently using steady-state model; anticipate moving to a dynamic model
- Results to date published in a series of EPRI reports

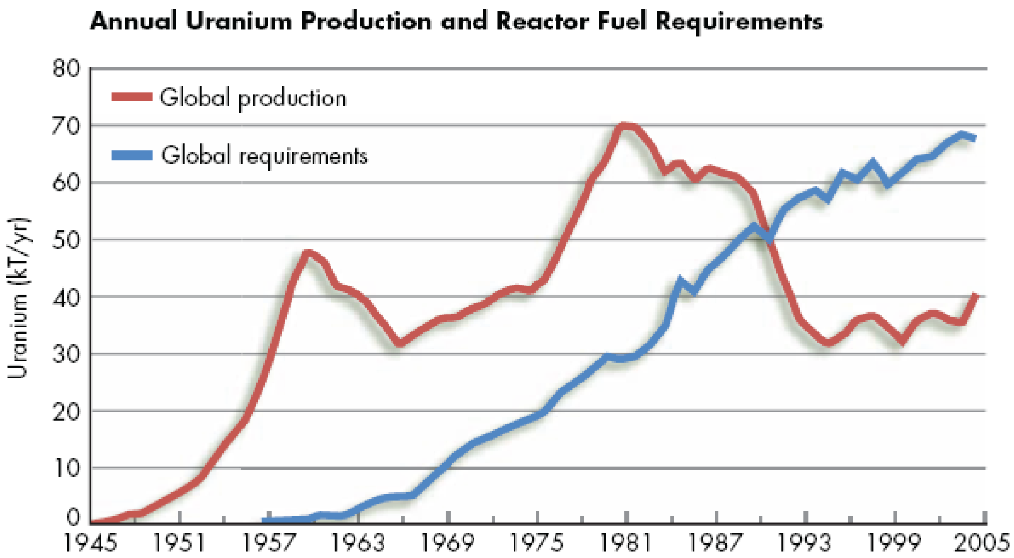
Fuel Cycle Economics at Steady State



For scenarios with high uranium prices, recycling of plutonium as MOX becomes economically feasible as long as reprocessing and fast reactor costs are kept low.

MOX Use Drivers, Constraints, and Concerns

- Regulatory environment
- Energy security
- Nonproliferation
- Public opinion
- Resource utilization
- Waste management
- Economics
- **Technology**



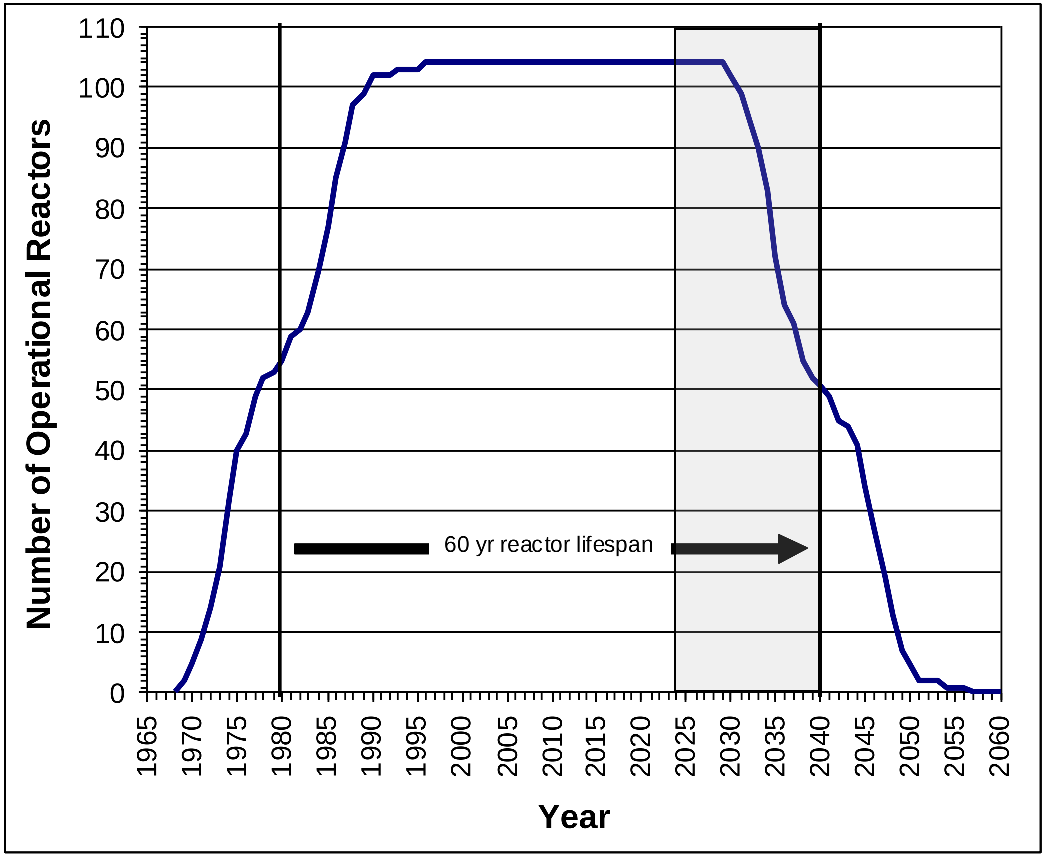
MOX Irradiation in U.S. Reactors

Reactor	PWR/ BWR	MOX Lead Test Assembly Start	Total Number of Assemblies	Total Number of Fuel Rods
Vallecitos	BWR	1960s	--	≥ 16
Big Rock Point	BWR	1969	16	1248
Dresden-1	BWR	1969	11	103
San Onofre-1	PWR	1970	4	720
Quad Cities-1	BWR	1974	10	48
Ginna	PWR	1980	4	716
Catawba-1	**PWR**	**2005**	**4**	**full 17 x 17 assemblies**

Existing U.S. Reactors as Candidates for MOX

- Assumptions:
  - Commercial MOX use no earlier than 2020
  - 20-year minimum remaining lifetime
  - Greater flexibility in late GEN II reactors

- Result: ~50% of current fleet are potential candidates



Global MOX Supply

- Existing French and UK production capacity of ~235 MTHM/yr

- U.S. DOE MOX facility under construction ~70 MTHM/yr max

- Planned Japanese Rokkasho facility ~130 MTHM/yr

MOX use in the U.S. is supply limited, NOT reactor limited, for the next 20 – 30 years

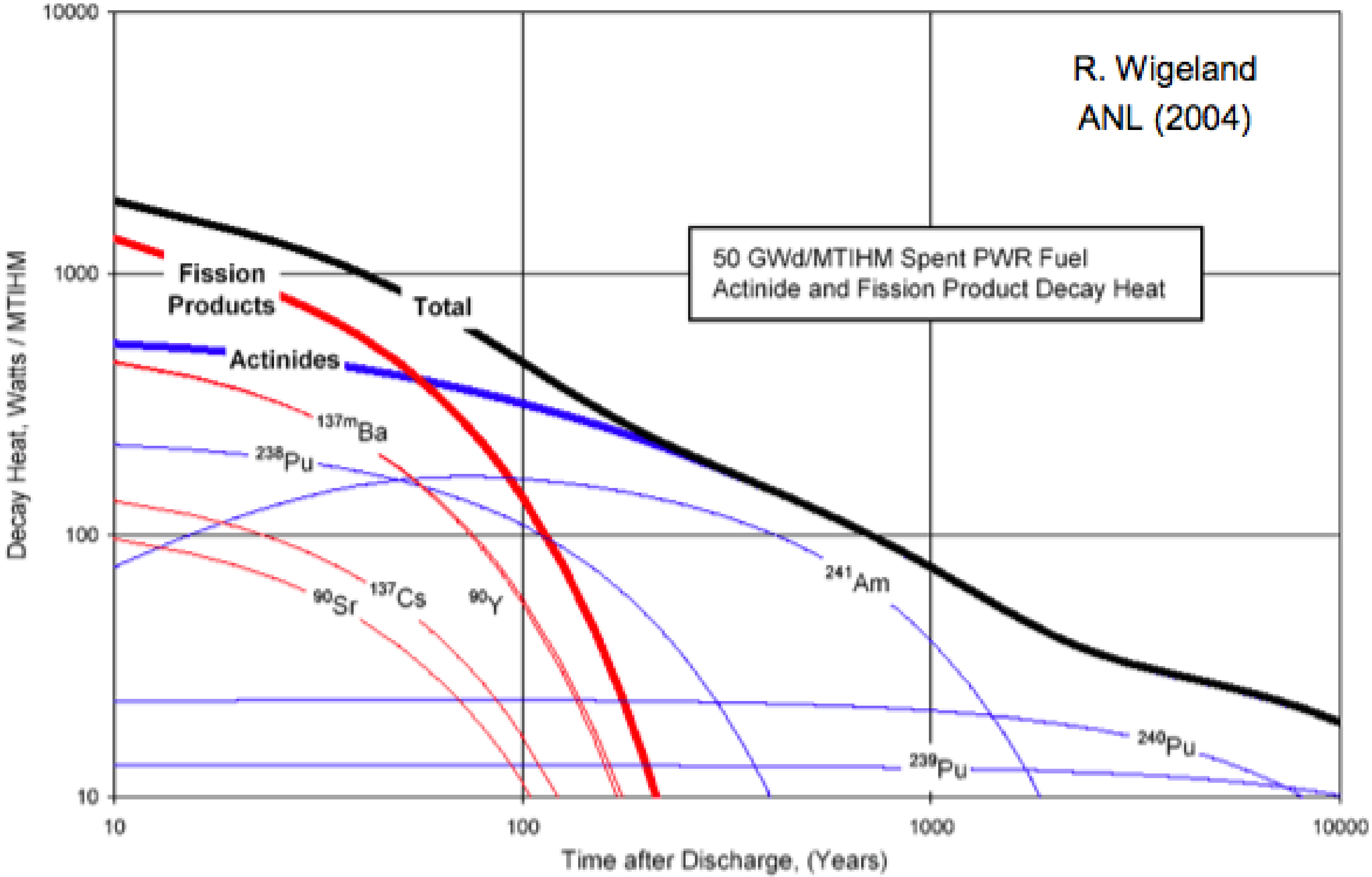
MOX Use Preliminary Findings
Existing Reactors

- No technical barriers identified to partial MOX loading (30% or less) in at least half of <u>existing</u> U.S. fleet
- Some modifications and operational changes possible
  - Amendment of reactor license (substantial but manageable)
  - Additional reactivity control
    - Higher soluble boron concentrations and/or enriched ^{10}B, burnable absorbers, or higher worth control rods
  - Plant-wide changes to address security, radiation protection and shielding, increased minimum cooling periods, spent fuel criticality
- No negative impact on return to 100% UOX cores

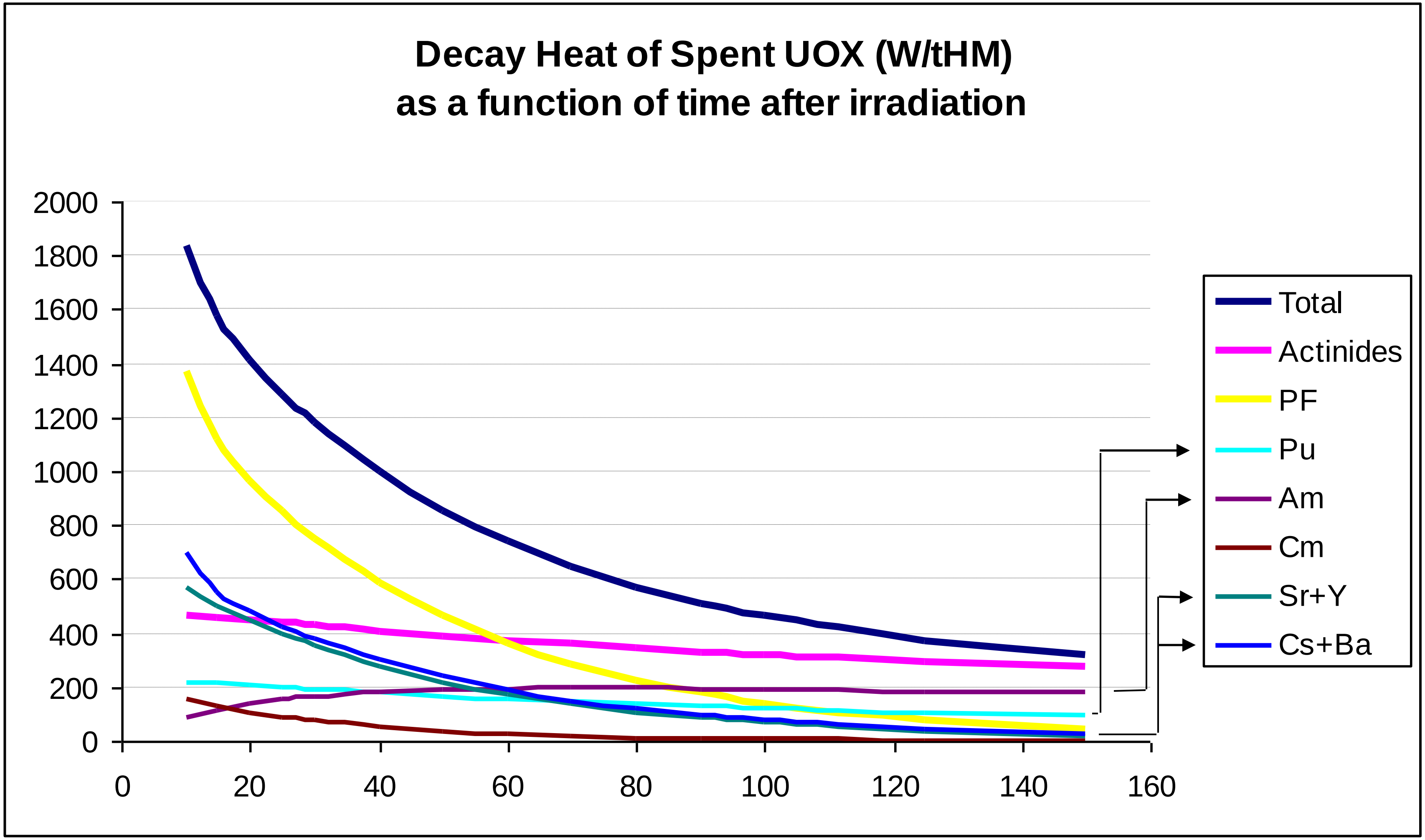
MOX Use Preliminary Findings
GEN III/III+ Reactors

- All GEN III/III+ designs *should* accommodate high MOX core loading (50% to full cores)
  - Full MOX core capacity reported for ABWR, AP1000, US-EPR, US-APWR
  - 50% MOX core loading target per European Utility Requirements
  - Core loadings of 50% or greater generally require MOX-specific design
- MOX use in new reactors may be restricted due to plant specific design aspects (e.g., spent fuel pool capacity)

Decay Heat Impacts Our Ability to Store, Transport, and Dispose of Used fuel and HLW

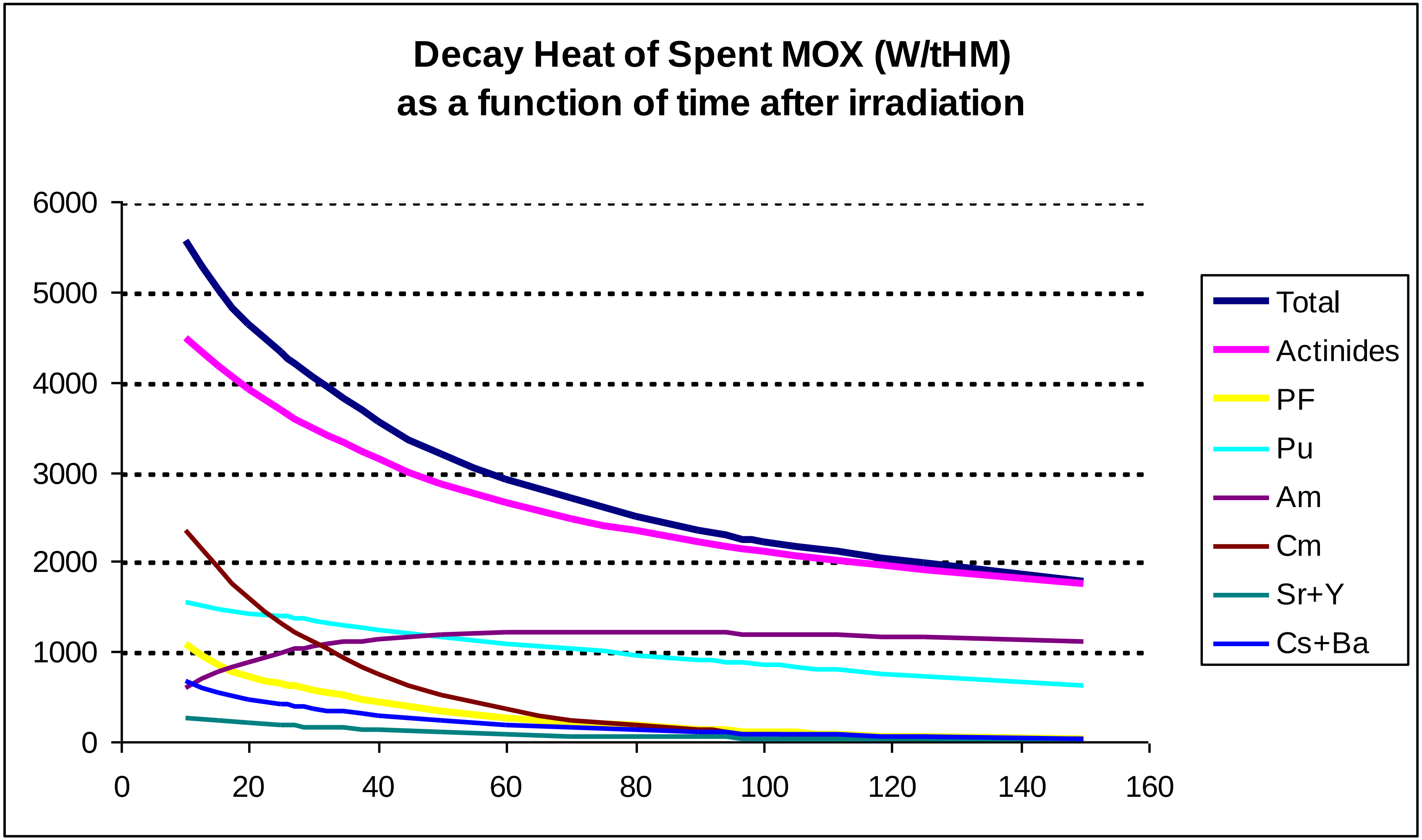


Decay Heat from Used UOX Assemblies



Source: EDF (July 2009)

Decay Heat from Used MOX Assemblies



Source: EDF (July 2009)

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Conclusions

- Much to be done to develop an industry with advanced fuel cycles
  - R&D important to enable well-informed decisions
- Current fuel designs more reliable, but approaching burnup limits
  - Need fuel design evolution for much higher burnups (e.g, SiC)
- If desired and available, MOX can be used in existing and next-generation reactors
- Fast reactor technology R&D first, then reprocessing
- Actinide reduction in the entire closed fuel cycle takes decades

Together…Shaping the Future of Electricity

ELECTRIC POWER RESEARCH INSTITUTE

A Selection of EPRI Reports on Advanced Fuel Cycle Topics

- NP-7261 "An Evaluation of the Concept of Transuranic Burning Using Liquid Metal Reactors" (March 1991)
- TR-100750 "Transuranic Burning Issues Related to a Second Geologic Repository" (July 1992)
- TR-106072 "A Review of the Economic Potential of Plutonium in Spent Nuclear Fuel" (February 1996)
- 1013442 "An Updated Perspective on the US Nuclear Fuel Cycle" (June 2006)
- 1015129 "Program on Technology Innovation: Advanced Fuel Cycles – Impact on High-Level Waste Disposal" (December 2007)
- 1015387 "An Economic Analysis of Select Fuel Cycles Using the Steady-state Analysis Model for Advanced Fuel Cycle Schemes (SMAFS)" (December 2007)
- 1016643 "Program on Technology Innovation – Impact on High-Level Waste Disposal: Analysis of Deployment Scenarios of Fast Burner Reactors in the U.S. Nuclear Fleet" (December 2008)
- 1018514 "A Strategy for Nuclear Energy Research & Development" (January 2009)
- 1018575 "Nuclear Fuel Cycle Cost Comparison Between Once-Through and Plutonium Single-Recycling in Pressurized Water Reactors" (February 2009)
- 1018896 "Program on Technology Innovation: Readiness of Existing and New U.S. Reactors for Mixed-Oxide (MOX) Fuel" (May 2009)

2010 Deliverables

- Parametric Study of Front-End Nuclear Fuel Cycle Costs Using Reprocessed Uranium [1020659] – February 2010
- Nuclear Fuel Cycle Cost Comparison Between Once-Through and Multiple - Plutonium Recycling in Fast Reactors [1020660] - March 2010
- Advanced Nuclear Fuel Cycles – Main Challenges and Strategic Choices [1020307] – December 2010
- Reprocessing Technology Primer – December 2010

ELECTRIC POWER RESEARCH INSTITUTE